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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 255

THE CATHODE OSCILLOGRAPH FOR THE STUDY OF LOW, MEDIUM AND HIGH FREQUENCIES.

By A. Dufour.

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THE CATHODE OSCILLOGRAPH FOR THE STUDY OF LOW, MEDIUM AND HIGH FREQUENCIES.*

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The object of this work has been to construct an apparatus for obtaining oscillograms of voltages and currents which are variable with respect to time and of the frequency which is constantly met in radio.

The principle of the method has been published previously (in C.R.t 158, p.1339). My first apparatus was made before the war and gave good results between 10,000 and 750,000 cycles but was not very easy to handle. The second apparatus, which was more easily handled and capable of use from low frequency to high frequency by the addition of the classical recording cylinder for the low frequency, was described in the Journal de Physique, (November, 1920) and in the Bulletin des Inventions (1922).

*The above translation of an article on the "oscillograph cathodique" was taken from Nos. 11, Nov. 1922, 12, Dec. 1922, 13, Jan. 1923, of "L'Onde Electrique." The translation given is not complete. The original article contains considerable information on the production of electrical oscillations, and is of particular value to those engaged in high frequency electrical investigations. Only the portions of the article dealing with the construction and use of the apparatus have been translated, the author's style and arrangement being retained as far as possible. The translation was made by Mr. H. E. Miller, of the technical staff of the Langley Memorial Aeronautical Laboratory, as the article is of particular interest because of the possibility of employing the apparatus described as an indicator for use on high-speed internal combustion engines.

The apparatus described in this memo is the result of a long study which was delayed by the war and lack of means despite the aid of the Service des Inventions which desired to use the apparatus.

Principle.

In order to make clear the use of the oscillograph, I will review in a few words the principle of the Braun tube from which it has been derived:

A stream of cathode rays emitted normally by a cathode travels in a straight line in the tube, going further as the vacuum is increased. A metallic shield containing a small hole allowing only a small portion of the electrons to pass through, produces a brilliant spot on a fluorescent screen placed in their path. An electrostatic or magnetic field placed between shield and screen will cause this spot to be displaced due to the deviation produced by these forces acting on the moving electron. If these fields vary in strength and direction with time, a bright line will be seen on the screen. If uniform transverse motion is given to the spot, there will be seen the cycle of events, which can also be photographed.

Let θ = deviation, H = intensity of magnetic or electric field, e = charge on electron, m = its mass, L = length through which the action occurs and v = velocity of the electron. Then the deviations are:

$$\theta = \frac{He}{m} \frac{L}{v^2} \text{ in an electrostatic field.}$$

$$\theta = \frac{He}{m} \frac{L}{v} \text{ in a magnetic field.}$$

Because of the negligible mass of the electron, the deviations given, as far as can be observed, are exactly the variations in the fields studied, even in the high frequencies where the inertia of mechanical system causes failure in the ordinary oscillograph. Besides its use as an oscillograph it can be employed to determine a difference of phase of two systems having the same frequency by having two fields operate directly at right angles to each other on the tube, one tube fed by the first system or circuit and the other by the second circuit.

Several methods of spreading out the oscillations in a transverse direction are used to suit the frequencies studied. These will be explained as they are reached. Since the emission of electrons is discontinuous, a question might be raised as to the possibility of discontinuous effect on the screen. As a matter of fact a little calculation shows that about 300,000 electrons reach each square millimeter of the plate per second so there is no visible discontinuity. While the value $\frac{e}{m}$ on which the formulae are based does not remain constant as the derivation requires, the change with velocity is not appreciable until near the velocity of light. As this is never approached even with the high velocities used here, this is not serious.

The oscillograph and accessories can be placed easily in a room about 20 feet long by about 15 feet wide. The only requirements are that the temperature be fairly constant and that it be possible to make the room dark. The room could be lighted by lights covered with a liquid screen of bichromate of potassium. The apparatus has been designed for use in a room lighted with white light but the other arrangement is preferable as it enables the loading, exposing, developing, fixing and printing to be done in the same room without danger of fogging.

Fig. 1 shows a diagram of the main portion of the apparatus taken through its axis of symmetry. The metallic bell jar (a) resting on the foundation plate (c) holds the cathode tube (d) and is closed by the door (b) through which pass several controls for the necessary mechanical operation within the bell jar. The jar supports a structure (x) which can rotate about a vertical axis and serve as a support for several circuits which act on the tube. Inside the jar a recording cylinder (g), which is covered by photographic film, revolves about a horizontal axis whose movement is controlled from the outside by a magnetic coupling (p) fastened to the shaft (q) of the interrupter (described later); this magneto-motive action takes place through the glass cap (o) and turns the shaft (n) fixed on the axis of the large air pipe, opening into the air channel through which the vacuum is produced. The removable recording cylinder is set in motion by a crank on the shaft (n) which engages a projection on the cylinder.

In order to record the time simultaneously, a luminous stream, arriving in the direction (r), passes through the glass (s) and, after being reflected by a total reflection prism (t) inside the jar, impinges on (u).

For high frequencies the cylinder is replaced by photographic plates shown schematically here in (h). It is necessary to place some phosphorus anhydride in the jar to insure drying the enclosure, especially when loaded with plates or film.

The cathode stream leaves the cathode (e), passes down the tube (d) to the diaphragm tube (f) which allows a wire-shaped portion of the stream to pass through into the region (v) where the magnetic or electric forces operate. In order to obtain an idea of the magnitude of deviations, a movable screen, covered with platino-cyanide of barium, pivoted about the horizontal axis (n), and controlled by the central valve of door (b), is supplied with the set-ups for high or low voltage. When this screen is in place it receives the impact of the cathode rays and through peepholes (i) covered with glass the magnitude of the deviations can be seen. By allowing the fluorescent screen to swing sideways the rays are allowed to follow their path and strike the film. To avoid fog the peepholes are painted red and can be covered by metallic shades if necessary.

The assembled apparatus must hold its vacuum as perfectly as possible, which has required very fine work as there are fourteen fitting surfaces or connections in the apparatus. Experience has shown that the obtaining of a vacuum suitable for proper operation of the tube is more rapid at the end of a period of operation than at the beginning, due to gases occluded in the metal being purged little by little. The apparatus is therefore kept under low pressure when not in use.

In operation great care must be taken of the fitting surfaces because a hard body compressed by a force of 700 kilograms (1543 pounds) due to the atmosphere would ruin the fitting surfaces of the door (b). At each closing the surfaces are greased with vaseline.

Cathode Tubes.

Various forms of tubes that can be used are shown in Fig. 2. Lower surface of tube A fits on the upper surfaces of the other tubes which in turn fit on the bell jar. Combination AB is used to study magnetic fields. Deviations of 1 millimeter for a field of 30 gauss acting through 5 centimeters are obtained. AC is used for voltage curves. A millimeter deviation is obtained with 10 volts between plates 8 centimeters long and 5 millimeters apart.

AD is used when two electric fields are caused to operate on the stream. The condensers are at right angles to each other. Tubes E, F, G, each furnished with two A tubes are used to record simultaneously two currents or voltages or one of each. They can only be used in the low frequencies. The branches must be screened so that there is no reaction of one tube on the other.

There is some irregularity of action due to the fact that the instantaneous pressures in the two tubes are not the same. A precaution to be noted is that the bell jar should be heated before removing tubes as they are liable to be broken.

Apparatus for making the vacuum.

The vacuum must be renewed each time the apparatus is loaded with film, and a pump system to obtain this easily has been devised. The circuit is shown in Fig. 3. The preparatory vacuum is made by the auxiliary pump C with valve (k) open and the remainder closed. The tube (h) is drying tube. After the manometer (v) shows the highest vacuum which C can give, valve (k) is closed and valves (m) and (j) opened in succession. The mercury vapor-pump B then produces the high vacuum. Observation of the arc T shows the extent of vacuum. When work is started valve (m) should be closed before stopping the preparatory pump. Air is let in by opening valve (1). As it takes time to get pump B to function well, it is usually kept warm and running, discharging into tube (g) and through valve (n) when work is temporarily stopped. The glass tubing used has been arranged to avoid temperature stresses.

Recording cylinder for low and medium frequencies.

The dimensions of the cylinder are 150 millimeters (5.91 inches) in diameter and 50 millimeters (1.97 inches) in length. A fluorescent screen is fitting directly over the film. The film is, of course, held flat on the cylinder, which rotates at the rate of 10 turns per second. The curves would tangle up due to operation during several turns unless some method of longitudinal displacement were devised, such as a sinusoidal field would produce. Another method is to have the tube light up only during one revolution of the cylinder, which will now be described.

Interrupter for low and medium frequencies.

Fig. 4 shows a schematic drawing of the set-up. The interrupter Z is a flywheel with a helicoidal groove into which the finger (c) can be inserted. The arm (a) is pulled in the direction of the arrow (x). The rod (n), connected to (a) by the frictional connection (m), travels from (o) to (p) breaking the circuit of tube (t') and lighting tube (t), which is the one used for pictures. In order to keep voltages and currents constant it is necessary to use a tube (t') whose resistance is the same as that of (t).

The electric circuits are of two kinds. One is an arrangement to obtain high voltage by means of an electrostatic machine. The other uses a transformer with a rectifier. The electrostatic machine always builds up to the same polarity, because a negatively charged plate is held opposite the upper end of the cross piece of the machine. This plate is charged by a transformer and rectifier. The electrostatic machine gives best results but has very small power. The transformer can give voltages up to 60,000. A steadying condenser must of course be used with the transformer, to give more constant voltage.

Sectors (k) and (l), in arm (a) Fig. 4, are used with brush contacts to operate, automatically, switches starting the phenomena studied. Slot (g) Fig. 4, is used in connection with the exact measurement of the speed of rotation of the cylinder which, as is seen in Fig. 5, is on the same shaft with the interrupter. Referring to Fig. 5, the method of speed measurement is very easily seen. Light from a nitrogen lamp S goes through (f) a slot in the prong of a tuning fork and is then converged by a lens L through the slot (g) Fig. 4. From there it enters the bell jar and is reflected on to the recording cylinder. As it can only enter through the slit (f) Fig. 4, vibration of the tuning fork permits only periodic flashes on to the film. The period of the fork is known so that the speed can be obtained. This completes the description of the method used ordinarily for low and medium frequencies. In extending the method to damped waves of high frequency a special switch is added.

Mercury, from tubes (f) and (f'), (Fig. 6), flows through the nozzles (e) and (e'). When the insulated metallic arm on the disk (d) comes around, it makes contact with the mercury, closing the circuit for the short period of time required. The break is made without an arc.

A third method for low frequency involves the use of a constantly decreasing magnetic field, such as is obtained by opening a current containing iron, to cause a displacement of the spot across the cylinder so that a helix is produced on the film. On this helix is superposed the curve of phenomena studied. It can be used up to frequencies of 11,000 per second.

Equipment for high frequencies.

For high frequencies a set of photographic plates is used instead of the recording cylinder and the interrupter. The plates, 6 in number, are 130 mm (5.12 in.) long and 125 mm (4.92 in.) wide. By means of a control on the door of the bell jar a plate which has been exposed can be dropped, so that it is no longer exposed, to make way for the next plate.

Method of recording.

As the photographic plates are stationary, the displacements on the plates are obtained by the action of electrostatic or electromagnetic forces. In Fig. 7 (I), the letter T marks the motionless cathode spot. II shows the line drawn by large oscillations, here called Y. III shows the line drawn by the smaller oscillations, here called Z. IV shows another line produced by oscillations Z'. Finally V illustrates a line obtained by a sweeping action X produced by breaking a magnetic circuit containing iron. VI shows a combination of X and Y actions. VII shows a combination of X, Y and Z actions. VIII shows a combination of all the actions X, Y, Z and Z'. IX is a vectorial presentation of the various actions.

In taking a record of high frequency phenomena the sweeping action X and an oscillatory Y action are used as accessories to the Z phenomena studied. The Y oscillations of large amplitude serve to lengthen out the record. I_n the highest frequencies Z are also accessory oscillations and Z' are those studied. Since the sweeping action is very fast, the tube need only be lighted a very short time; which helps to preserve the tube and enables it to be used under the highest voltages.

The power required is too great for my electrostatic machine, compelling the use of a transformer and rectifier. It is necessary that the tube be used when the voltage supplied is the right part of the cycle for operation of the tube. By means of a synchronous motor this is accomplished. All the switching operations are done satisfactorily by an automatic system shown in Fig. 8.

The arm (b) is held clear of switches 1 to 5 by the spring (e). At the right moment, indicated by the ringing of a bell, a trigger is pulled, releasing the arm (b), which operates all the switches in the order 1 to 5. Adjustments of the positions of the switches allow considerable control of the timing of the various circuits.

Both this circuit and the arrangement for low and medium frequencies have given very satisfactory results. Several sample oscillograms of the work done by the low frequency arrangement are included at the end of this report. Fig. 9 shows the current time curve for opening and closing of an electric circuit containing an air inductance. E to R is the shape of the current time curve on closing the circuit. The oscillatory portion beyond R is the oscillatory discharge which takes place across the air gap at the point where the circuit is broken.

Fig. 10 shows a continuous wave alternating current whose frequency is 11,000 cycles per second. Fig. 11 is an oscillogram of damped waves with a frequency of 1,100,000, while Fig. 12 shows the current time curve for an antenna tuned to receive waves whose frequency is 115,000. The waves are damped oscillations from a spark transmitting set.

While no illustrations of the work done by the high frequency arrangement are included in this translation, the original article shows as good oscillograms for higher frequency. The range of the low frequency arrangement is from 0 to 50,000 for sustained oscillations and from 0 to several million for damped oscillations while the high frequency arrangement can be used from 10,000 to 10,000,000 for continuous waves and for damped waves has reached 220,000,000 cycles per second.

In combination the oscillograph can furnish oscillograms of currents and voltages from 0 to 10,000,000 cycles per second for sustained waves and 0 to 220,000,000 cycles per second for damped waves, which includes every frequency used from the lowest to the highest. It therefore has no practical limit.

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Figs.1 & 2.

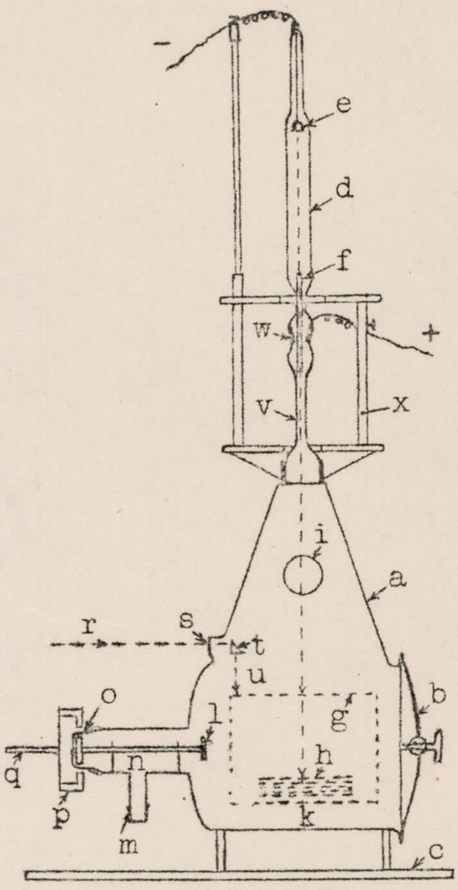

Fig.1.

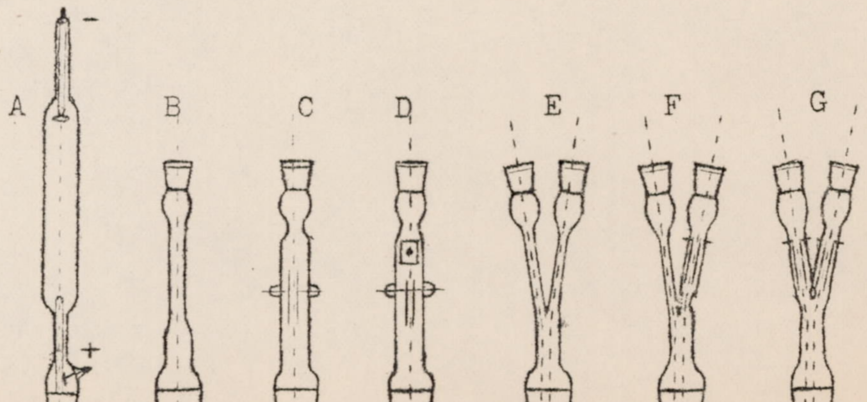

Fig.2.

Figs. 3 & 4.

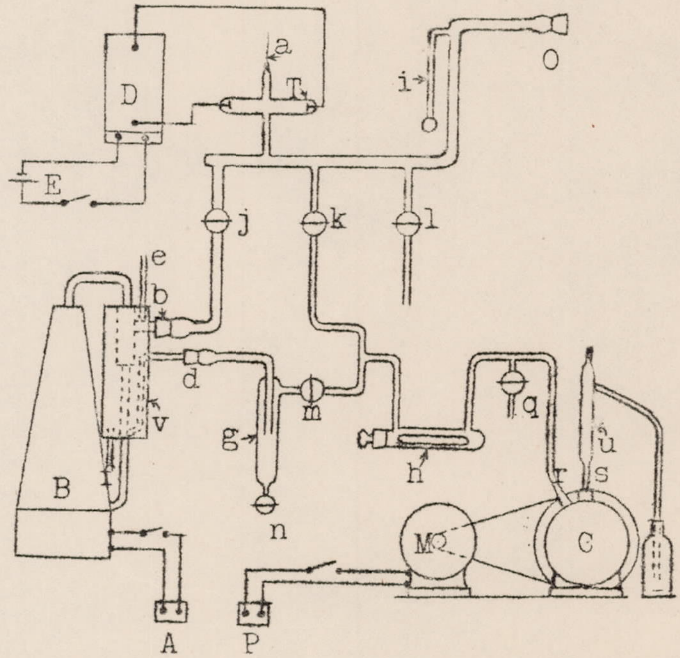

Fig. 3.

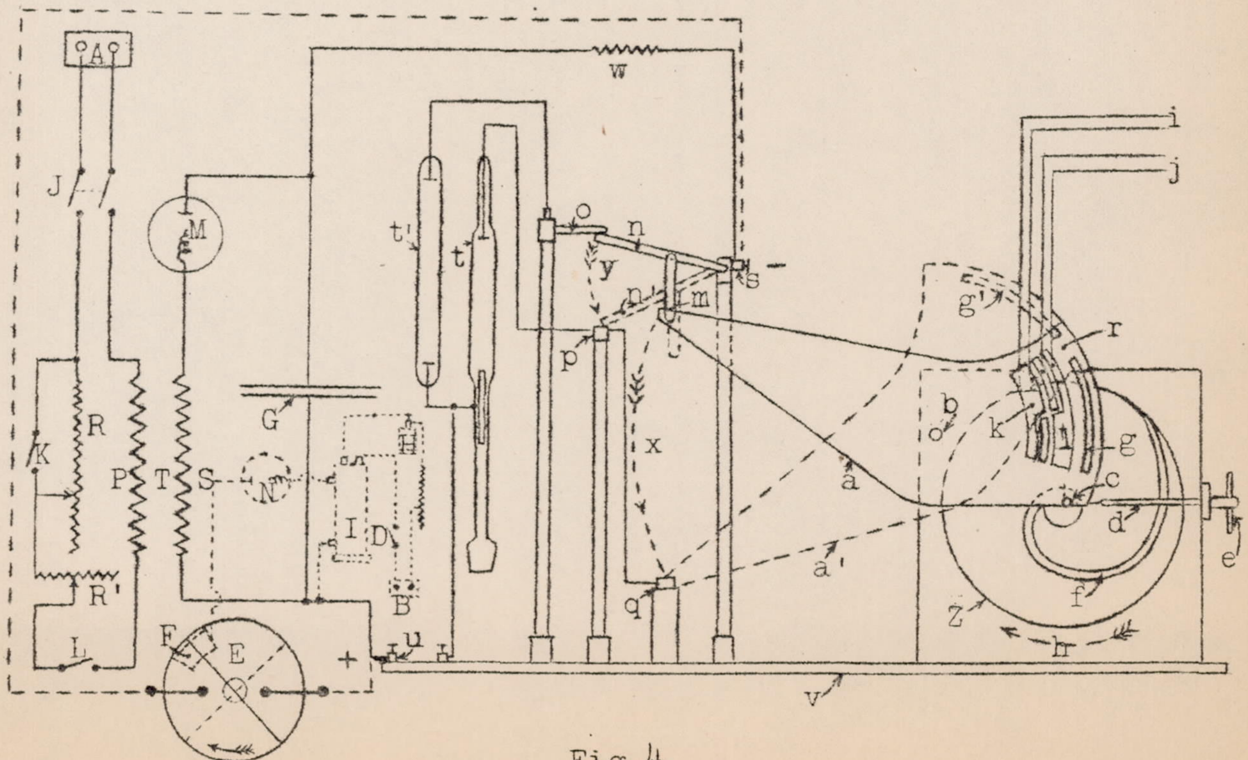

Fig. 4.

Fig.5

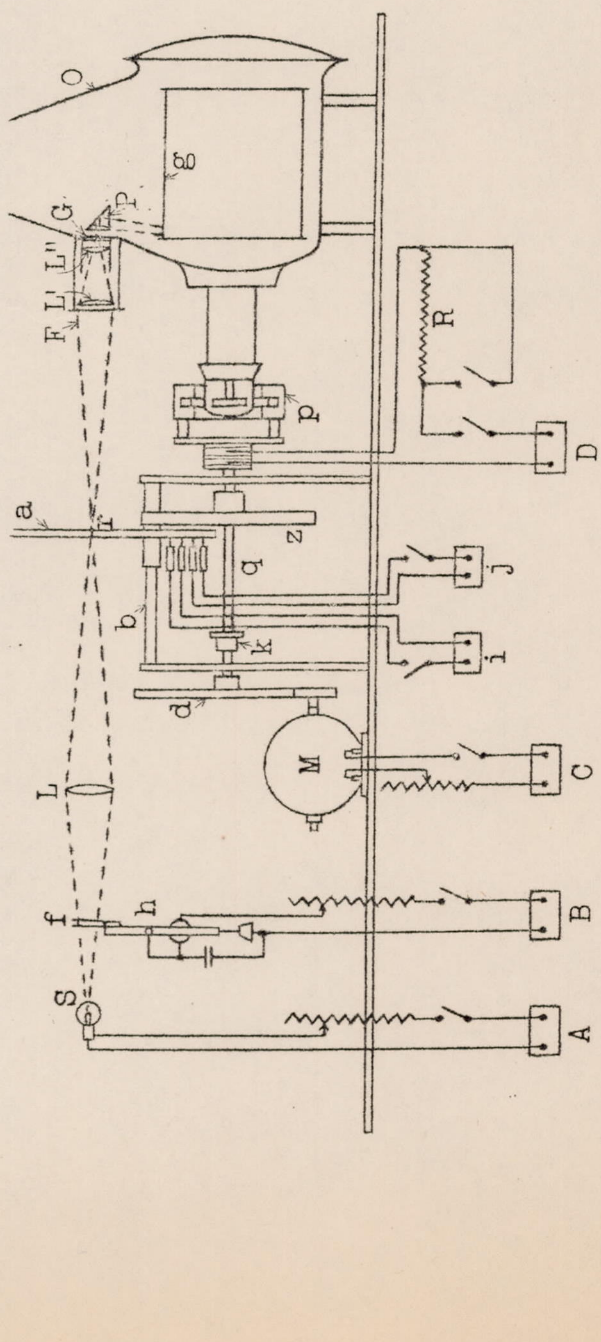

Fig.5

Fig. 6,7.

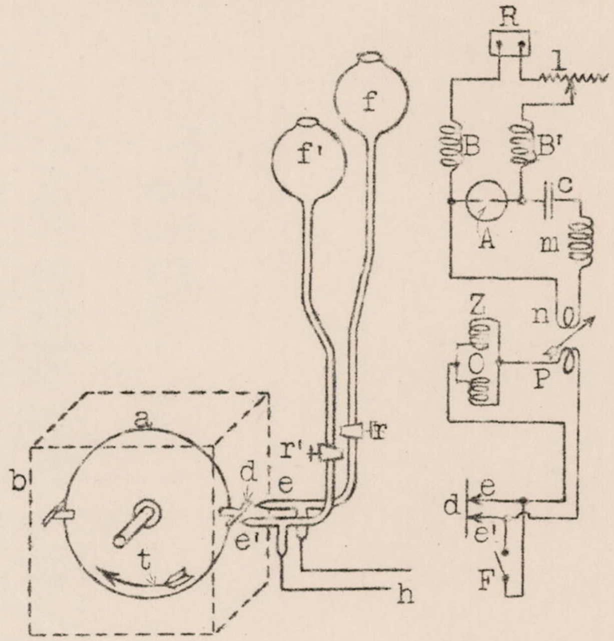

Fig.6

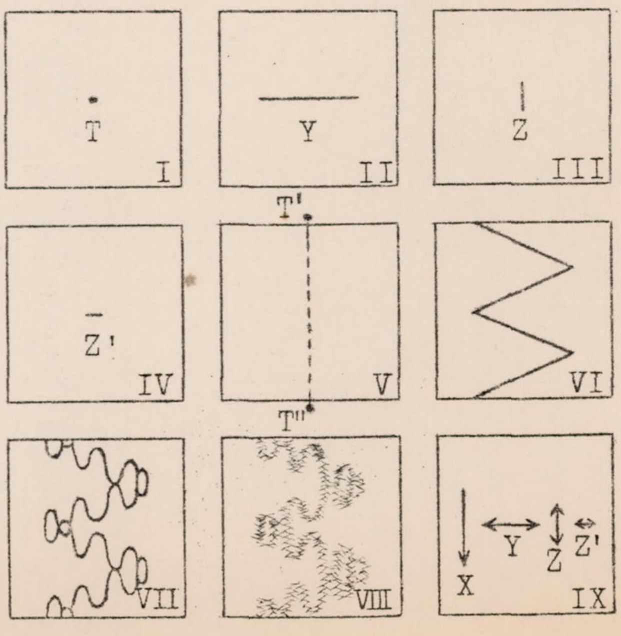

Fig.7

Fig.8

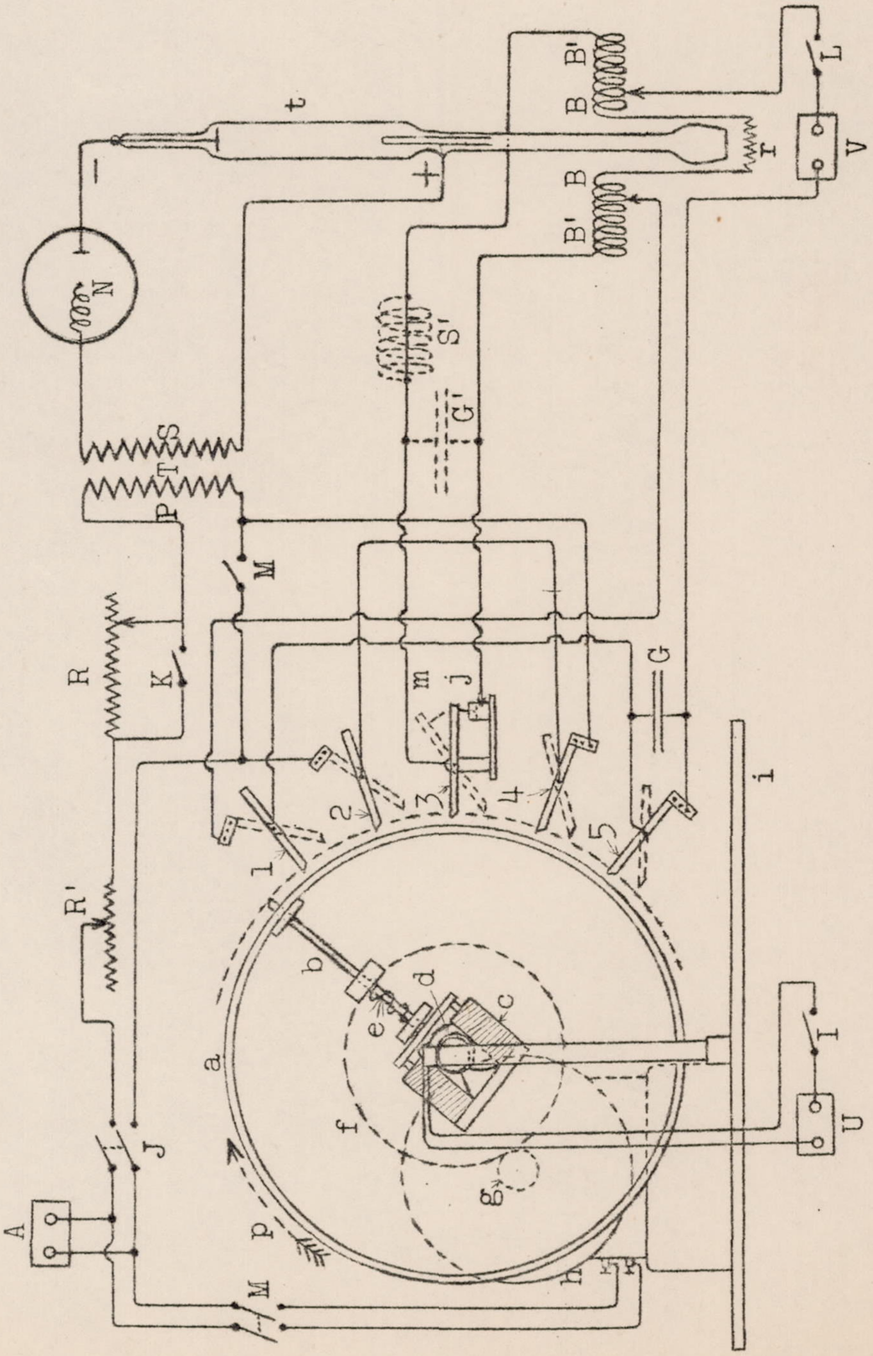

Fig.8

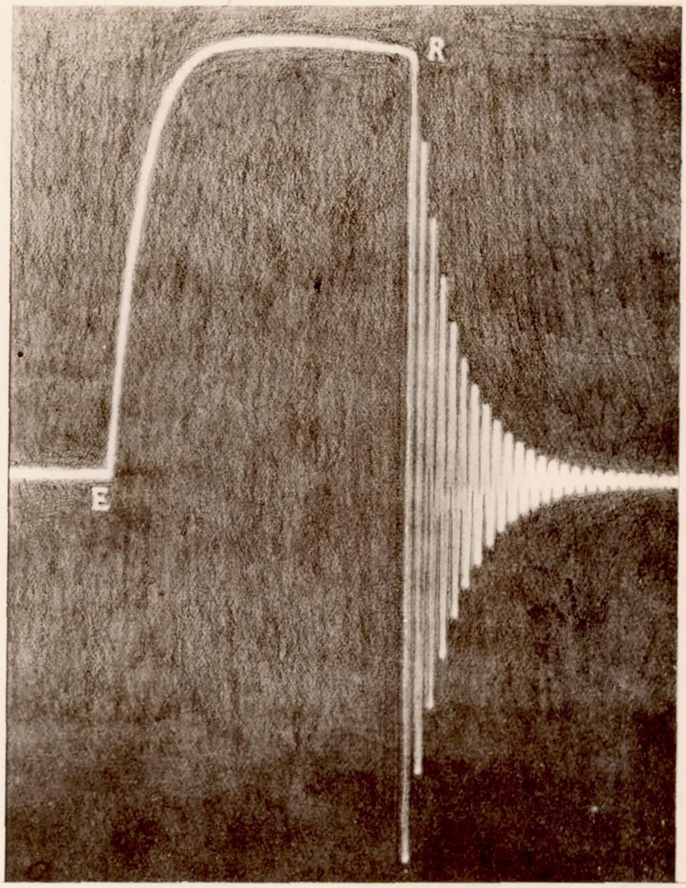

Fig.9 The making and breaking of a direct current. Circuit contains self inductance without iron, and a condenser at the period of break.

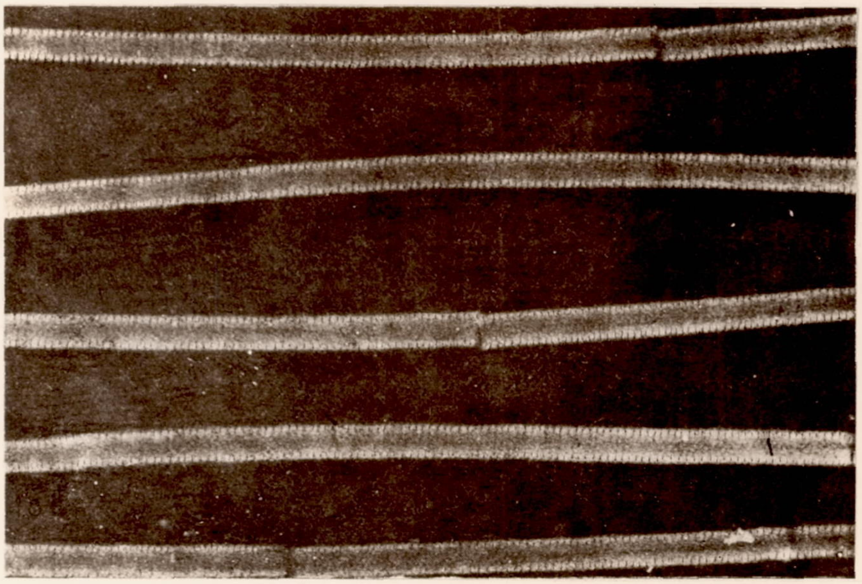

Fig.10 Damped waves - Current curve. Frequency = 11,000 cycles.

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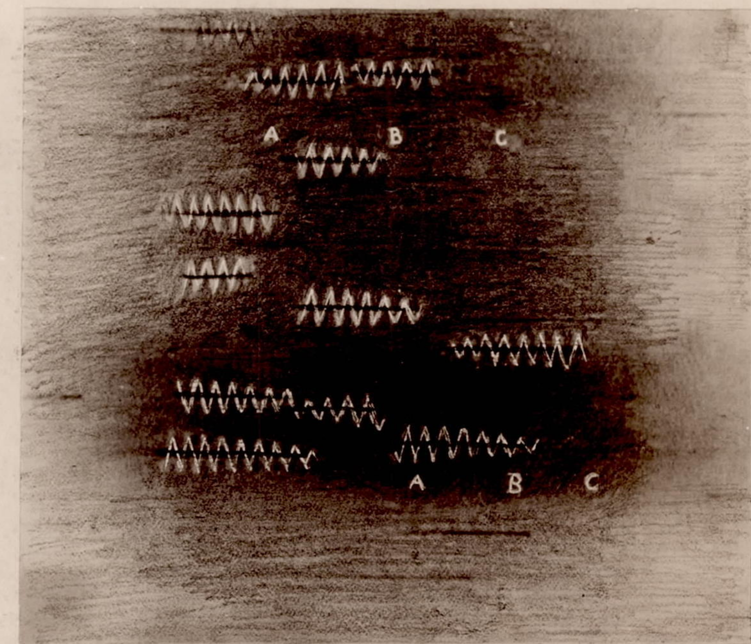

Fig.11 Damped oscillations - Current curve.
Frequency = 1,100,000 cycles; = 285 m.

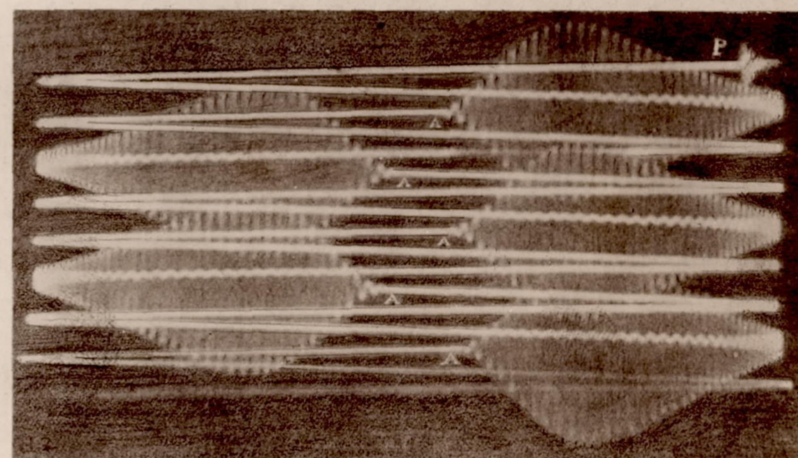

Fig.12 Current in an antenna in receiving damped waves from the Eiffel Tower.
Frequency = 115,000 cycles; = 2600 m.

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